KAPITZA CONDUCTANCE AND THERMAL CONDUCTIVITY OF MATERIALS USED FOR SRF CAVITIES FABRICATION

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Abstract

A dedicated apparatus was developed for measuring at low temperature the thermal conductivity of different materials actually used for the fabrication of SRF cavities. This device allows the test of four samples simultaneously. Several samples of different materials (Nb sheets, Ti…) were either tested as received or/and subjected to various Heat Treatment (H.T) then tested. Another test facility was used for the characterization of heat transfer between different materials and superfluid helium in the Kapitza regime. Kapitza resistance measurements were performed on several niobium specimen either uncoated or coated with thermally sprayed layers of different materials (Cu, Ti .....) in the temperature range 1.5 K - 2.1 K. The influence of different parameters such as Nb initial purity (RRR) , Nb heat treatment at 800° C or at 1200 ° C with Ti gettering , Nb and/or coating surface preparation and treatment on both thermal conductivity and Kapitza conductance was investigated. We report also the effect of the coating on Kapitza conductance. Finally, our experimental data are compared to results previously reported and the effect of the coating on the SRF cavities ultimate RF performance and thermal stability is discussed.

1 INTRODUCTION

In order to reduce the cost of the TESLA machine and reach the ultimate 800 GeV center of mass energy regime, it is needed to increase the accelerating field design value from the actual one (i.e E_{acc}=22 MV/m) up to 34 MV/m. To reach this goal, thermal breakdown or quench, which is the main bulk niobium SRF cavity limitation must be overcome. High purity Heat Treated (H.T) niobium must then be used for cavity fabrication. However, a recent study [1] showed that in such conditions (i.e soft H.T Nb), the actual EB welded stiffening rings are not sufficient to keep the cavity detuning induced by lorenz forces below the cavity bandwidth for E_{acc}>28 MV/m. Consequently, alternate stiffening schemes and new cavity fabrication methods must be developed. A R&D program was initiated since 3 years between the three French laboratories (Orsay/Saclay). The proposed method while the cold source (LHe) is maintained at T_{bath}. Precise measurement of T_{sink} is performed by means of a reference Germanium thermometer absolutely calibrated to within ±5 mK in the temperature range 1.5 K – 20 K. Note that this thermometer is also used for referencing all the thermometers at the thermal equilibrium (q=0) and under isothermal conditions. Furthermore, T_{bath} is also regulated via the control of the LHe bath vapor pressure (two MKS capacitive pressure sensors (0-1000 Torr F.S and 0-100 Torr F.S) and automatic valve with a PID regulator) and monitored with another calibrated reference Germanium thermometer.

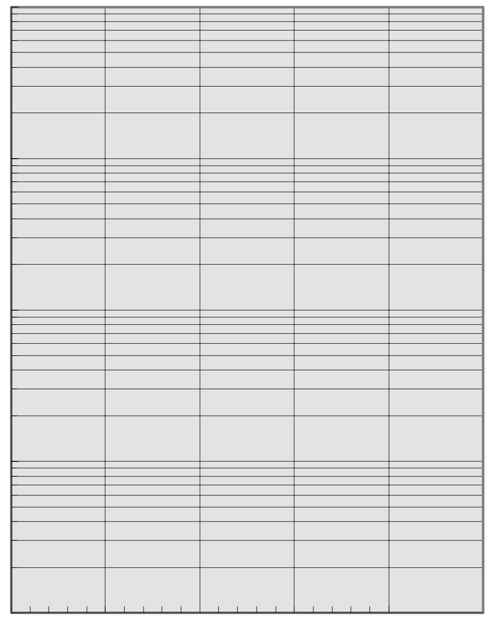
2) Four test-samples (length = 55 mm, width = 10 mm, thickness = 0.3 mm to 3 mm depending on the specimen) which are measured simultaneously during each experimental run. Each of these test-samples is equipped with a removable heat source attached to its lower extremity and four calibrated (1.5 K – 60 K) Allen-Bradley carbon resistors. Three of these thermometers are used to measure the temperature gradient along the test-sample. Note that as the experiment is performed at low heat flux, it is more reliable to use three temperature sensors instead of two (linear temperature profile along the sample). Moreover a special attention was given to thermometers mounting and thermal coupling to the sample : we used a knife edge–like O.F.H.C copper clamps with a copper filled grease (thermal bonding agent) and careful thermal anchoring of thermometer leads to the sample. It has to be stressed that the thermometers leads were carefully thermal anchored at different locations (thermometer location, heat sink, then LHe bath) so as to improve the accuracy of temperature measurement. The fourth thermometer is used for measuring the heater temperature in order to estimate the heat leaks from the heater to the surrounding. The heat source which consists of a Joule heated O.F.H.C Cu block with manganin wire wrapped around is also mounted on the sample using a copper filled thermal conductivity grease to improve thermal contact. Finally the test-samples are fixed and thermally clamped to the heat sink at their upper extremity.

3) Two O.F.H.C copper radiation shields coated with one layer of superinsulation surround the heat sink as well as the test-samples. The innermost radiation shield, which is thermally clamped to the heat sink, is directly placed around the test-samples. The second radiation shield is thermally attached to the brass rod at an intermediate temperature between T_{bath} and T_{sink}.

4) The whole assembly is placed inside a stainless-steel vacuum insulating jacket.

Note that as the major parts of this system are removable, a special care was given to insure proper clamping and good thermal contact: all copper pieces were first cleaned and deoxidised then coated with high conductivity grease just before each mounting operation.

Several specimens were tested : niobium sheets from different suppliers with initial RRR ranging from 30 to 250 was measured as received and after Heat Treatment at 800°C and/or 1200°C with Ti gettering, under normal Atmosphere Plasma Sprayed (APS) copper coating and niobium-zirconium alloy supplied by DESY. As illustration, we present in Fig. 2 some of the experimental results obtained.



material including Kapitza resistance , measurement were performed on uncoated and coated Nb disks using the test-cell described in a previous paper [1].

3.1 Uncoated Niobium

All the uncoated niobium samples were tested as received (i.e without any Heat Treatment). The Kapitza conductance h_K is defined by the well-known equation :

$$h_K = \lim_{\Delta T \to 0} \frac{q}{\Delta T} \qquad (1)$$

where q is the heat flux density, ΔT the temperature jump at the Nb-He II interface and h_K the Kapitza conductance.
The Kapitza resistance experimental data R_K of all the Niobium specimen tested were fitted (least-square method) according to the usual power law :

$$R_K = \frac{1}{h_K} = a \cdot T_{bath}^{-n} \qquad (2)$$

where T_{bath} is the He II bath temperature .
The parameters a and n obtained experimentally are summarized in Table 1 .

Nb sample thickness (mm)	**RRR**	**a ($K^{n+1}.m^2/W$)**	**n**
Wah Chang 2	200	$2.7\ 10^{-3}$	2.85
Wah Chang 0.5	46	$1.2\ 10^{-3}$	3.46
Plansee#1 2	30-40	$1.5\ 10^{-3}$	3.13
Plansee#2 2	30-40	$2.5\ 10^{-3}$	4.64
Heraeus 1	140	$1.0\ 10^{-3}$	3.06
Tokyo Denkai 2.8	229	$7.4\ 10^{-3}$	2.97
Cabot 2	30-40	$1.6\ 10^{-3}$	4.68

Table 1 : Kapitza resistance parameters
(plansee#1 : mechanically polished, plansee#2 : chemically etched)

As expected, we observe a large variation concerning the fit parameters of the Kapitza resistance. This is mainly due to the different surface state conditions of the samples. Moreover, all these data are in the range of the values previously reported by different authors[2-3].

3.2 Coated Niobium

The experimental data of the equivalent thermal resistance R_{th} of a Nb cavity coated with a Controlled Atmosphere Plasma Spraying (CAPS) Cu layer (Cu thickness : 2 mm) versus uncoated niobium cavity (as received RRR=200 Wah Chang Nb sheet) at different temperatures is presented in Fig. 3.

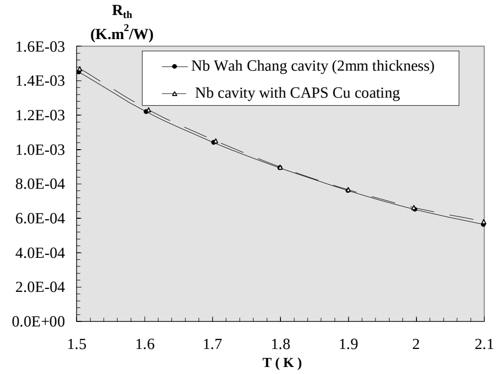


Fig. 3 : Effect of the CAPS Cu coating on the cavity thermal resistance

These data clearly show that the CAPS Cu with 10%

with a 2.6 mm thick High Velocity Oxy-Fuel (HVOF) Cu layer. The resulting high thermal resistance of this sample could be attributed to the heavy oxidation of the Cu layer and its low porosity (2.8%). A new test-cell for measuring bad thermal properties samples is under development and the corresponding data will be published in the future. Some conclusions could be drawn from the above results . The difference observed between the overall thermal resistance of uncoated cavities are mainly due to the niobium thermal conductivity and thickness. The thin bonding layer (CuAl) alloy which as initially used in the APS process to improve the bonding strength between Nb and Cu increases dramatically the coating thermal resistance and should be avoided. Moreover APS or CAPS (produced under inert gas atmosphere : Ar) coating with high porosity (i.e >10%) have the lowest thermal resistance. However, their mechanical properties did not fulfil the requirement for cavity stiffening [4] in cw mode at E_{acc} = 40 MV/m (too low Young Modulus). It seems that the coating which could fulfil thermal and mechanical requirements must have a low porosity (<3%) and sprayed either under Inert gas atmosphere or under vacuum to avoid oxidation. Work is in progress to achieve these goals in the near future.

4 REFERENCES

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